FISH NUTRITION AND AQUACULTURE WASTE MANAGEMENT

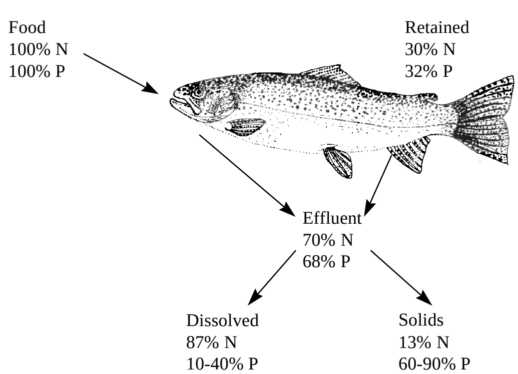
Laurel J. Ramseyer and Donald L. Garling
Department of Fisheries and Wildlife
Michigan State University
East Lansing, MI 48824

Introduction

Aquaculture activities can have a significant effect on the health and quality of receiving waters. Changes in oxygen, temperature, pH, and the addition of metals, drugs, suspended solids, ammonia, organic nitrogen, and phosphorus are often measurable downstream from hatcheries. The impact of farm discharges on the receiving waters depends, in part, on the level of nutrients already present.

In the North Central Region, where most lakes and streams are already nutrient-enriched (mesotrophic or eutrophic), the addition of farm wastes is usually considered detrimental. Phosphorus (P) and nitrogen (N) in farm wastes primarily originate from feeds and are of greatest concern due to their role in nutrient enrichment (eutrophication). Eutrophication is the artificial enrichment of waters which often results in blooms of noxious algae or excessive growth of higher plants. When the plants die, the decaying organic material can deplete water of oxygen to a degree detrimental to other aquatic organisms.
The primary sources of aquaculture wastes are from fish excretion and uneaten feed. Only about 30% feed N and P are retained by salmonids fed most commercial feeds EVEN IF THEY CONSUME ALL OF THE FEED FED. Feed N and P not retained by the fish are excreted (Figure 1). The purpose of this presentation is to provide aquaculturists with strategies for minimizing farm wastes through feed formulation, feed selection, feeding management, and solid waste management strategies.

Fate of feed nitrogen (N) and phophorus (P)



Feed Formulation

Interest in the culture of many fish species, such as yellow perch and sunfish, has out paced research on their nutritional requirements. As a result, aquaculturists often must feed commercial feeds which were formulated for other fishes like trout and catfish. This strategy is generally successful in terms of growth and fish health, but may result in unnecessary waste when dietary nutrients exceed the species requirements.

Commercial feeds are often formulated to contain a slightly higher level of a nutrient than is required by the species for maximum growth. The extra nutrients are added to feeds because few if any feed ingredients are completely digested and absorbed and serves as a safety margin to insure that requirements for maximum growth are met. Unfortunately, these safety margins contribute, in part, to the production of excess wastes in fish farm effluents.

Nitrogen

Most feed N is found in amino acids, the basic units of protein. Intestinal enzymes break down feed protein into amino acids which are absorbed and used to build new proteins such as muscle. Excreted N comes from several sources, including undigested and unabsorbed dietary protein, sloughed intestinal cells, amino acids absorbed in amounts greater than the fish can utilize, and degraded metabolic products.

Undigested and/or unabsorbed proteins are excreted in the feces. Fecal N can be reduced by developing feed formulations that meet the specific species requirements and feeding practices. However, most of the N excreted by fish is lost through the gills and is not recoverable. Excreted gill N originates from absorbed but unused amino acids and degraded metabolic products. Because excreted gill N is in dissolved form, balancing amino acid profiles to fit the specific species requirements and avoiding over-feeding are the best ways to minimize excreted gill N. Typical losses of metabolic N range from 100-200 mg $N \cdot kg\ fish^{-1} \cdot day^{-1}$ in salmonids and are unavoidable.

Since most N is excreted in dissolved form, typical management practices to control farm solids, like siphoning or solids settling areas, are not effective in reducing effluent N. Reducing the amount of excess N introduced into the system as feed is the only effective method to control N in fish farm effluents. Therefore, feed protein quality and quantity are important factors to consider in controlling effluent N. Protein quality refers to the balance and digestibility of dietary amino acids. There are 10 essential amino acids (EAA), which most fish cannot make and must obtain from their feed. A high-quality feed will supply the EAAs usually from high quality ingredients like fish meal and soybean meal. The ingredients must also be added in the proportion and quantity necessary to match the specific fish's requirements for metabolism and muscle growth. Feeding the appropriate level of protein comprised of amino acids balanced for another species results in increased effluent ammonia-N.

Lower quality feeds may be formulated with larger amounts of a poorly-balanced protein sources to meet the minimum EAA requirements. Similarly, feeds formulated with the proper EAA for one fish may not be properly balanced for other fishes. This results in the absorption of some amino acids in amounts beyond the fish's ability to utilize them for muscle growth. When more amino acids are absorbed than the fish can utilize, the N is removed and excreted via the gills as dissolved unionized ammonia (NH_3).

Fish size, protein intake, and temperature all affect the amount of ammonia excreted.

Young, faster growing fry generally require feeds containing higher percentages of protein. Even though relatively little feed N is put into the system for first-feeders, a larger percentage of it will be excreted because nitrogen excretion is inversely proportional to fish weight. Increasing temperatures effect N excretion by increasing voluntary feed intake and food movement through the gut while decreasing nutrient utilization. This is a problem if feeding to satiation or using demand feeders. Fish will usually consume more feed than required for optimal growth rate and nutrient utilization.

Some loss of N is unavoidable even when premium feeds are fed due to protein turnover in the fish and because enzymes that break down proteins are always active in fish. However, protein utilization for non-muscle uses is minimized by substituting calories supplied as protein by calories from carbohydrates or fat. This is called protein sparing because fish will then use fat or carbohydrates rather than protein for energy needs, thus sparing protein for muscle growth. High levels of dietary carbohydrate are usually not tolerated well by salmonids and should be avoided.

Phosphorus

Phosphorus is found in all plant and animal feed ingredients. The availability of P varies greatly depending on the source (Table 1). Excess dietary P is excreted in both solid and dissolved form (Fig. 1) and is therefore more amenable than N to solids collection techniques. However, feed-related P wastes can be minimized by using forms which are highly available to the fish yet have low water solubility.

Table 1. Percent availability of phosphorus in common feedstuffs.

Ingredient	salmonid	catfish	carp
blood meal	81		
brewer’s yeast	79-91		93
feather meal	77		
poultry by-product meal	81		
anchovy meal		40	
herring meal	52		
menhaden meal	87	39	
rice bran	19		25
wheat germ	58		57
wheat middlings	32	28	
ground corn		25	
dehulled soybean meal	36	29-54	

Most freshwater fish require 5-8 g $P \cdot kg^{-1}$ dry feed, but commercial feeds, because of the ingredients used in formulation, typically contain 10 g $P \cdot kg^{-1}$ or more. Fish meal, used in most fish feeds, contains bone which is a highly concentrated source of P, but it is not efficiently digested by fish. Recent advances in fish meal processing technology enables the removal of bone; however, this adds significantly to the cost of the meal. Soybean meal and other plant ingredients contain phytin, a plant P storage molecule. Phytin P is poorly digested by fish and other animals with simple stomachs. The undigested phytin P is excreted with the feces into the environment.

Feed Selection

Floating feeds should be used whenever possible. Floating feeds allow the aquaculturist to monitor fish feeding activity. In addition, floating feeds may be more water-stable than some sinking pellets. However, sinking feeds are generally less expensive than floating feeds and some fish species may be reluctant to actively feed at the surface.

It is good practice to feed the largest pellet size which is acceptable to the fish. Fish expend less energy during feeding if their feed needs are met by fewer, larger pellets. Larger pellets also have a smaller surface-to-volume ratio than smaller pellets which reduces the rate and amount of nutrients that leach into the water before the pellets are consumed. Feed 'dust' and particles too small to be consumed by the fish should be screened out prior to feeding. A high quality feed will contain < 1% fines.

Researchers and feed manufacturers are looking for improved feed binders and alternate processing techniques to improve feed stability. Certain feed binders may also improve fecal stability in water, thereby increasing the efficiency of solids removal.

Freshness

Feed bags should be checked for the expiration date. Care should be taken to avoid feeding older feed. Many key ingredients such as vitamins are unstable beyond the time designated by the manufacturer. Fish will not fully utilize the feed if it is deficient in nutrients due to break down over time which will increase the amount of waste produced by your fish. Most manufacturers recommend storing feeds in cool, dry conditions to maximize their shelf life. If feed is not purchased directly from the manufacturer, the purchaser should verify with the retailer that the feed had been stored properly.

Feeding

Poor feeding management can be an important source of farm wastes. Even perfectly formulated feeds will result in excess effluent nutrients if fish are over fed. Most feed manufacturers suggest feeding rates for their different feeds based on fish size and water temperature. Feed tables have also been published in National Research Council (1993) and Piper et al. (1982) for trout and catfish.

If given the opportunity, fish generally will consume more feed than they can use efficiently. For this reason, demand feeders should be avoided except under special circumstances such as feed training. If a demand feeder must be used, the amount of feed provided daily should be limited to feeding table values or established daily feeding rates for the farm.

Feeding schedules should be designed to account for fish behavior. Factors that affect of active feeding, such as light sensitivity or time of day, may influence feeding efficiency.

Estimating Nutrient Loading

The amount of N and P released in farm effluents is often estimated using water samples. The concentration of nutrients in farm effluents fluctuates frequently due to management practices and nutrient interaction with the air, bacteria and algae, and sediments. Since water sampling is expensive, samples may not be tested often enough to accurately reflect farm nutrient discharges.

Alternately, N loading may be calculated based on fish weight gain. Using this method, fish protein gain, based simply on weight gain, is mathematically translated into N gain. Subtracting the amount of N gained by the fish from the amount of N fed results in an N loss estimate. This simple calculation is possible because the amount of protein (or N) in a fish is directly related to its weight (Ramseyer and Garling, unpublished data).

If fish are excessively fatty, N lost will be underestimated. If final weights of individual fish are not similar or normally distributed about the mean, calculations must be made for subgroups of similarly sized fish.

Solid Waste Removal

Control of solid waste is important to reduce the level of P in fish farm effluents. Approximately 80% of the P in wastes from aquaculture is in solid form as feces or uneaten food. Intact fish feces and uneaten feed settle rapidly; but, can be easily broken into fine particles by fish movement and management activities. Solid wastes can be removed efficiently from hatchery raceways if the raceway and settling areas are properly designed. For example, raceway baffles or tube raceways can efficiently move solids to the settling areas. Settling areas must be physically separated from the fish and solids removed regularly. Significant amounts of P and other nutrients may leach from small fecal fragments within an hour because of the increased particle surface-to-volume ratio. Smaller fecal fragments may remain suspended in the water and may be too small for removal by filtration.

Collected raceway solids have a potential use as fertilizer. They are a slurry, containing approximately 80% water, which can be pumped from the raceway or settling basin. The methods and timing of application of fish farm solids to fields are important to ensure that the nutrients do not pollute surface waters. For example, fish farm wastes should not be applied over frozen ground or fields during heavy precipitation. Application of fish farm wastes may be regulated by states and may require permits. Check with your state Department of Agriculture for applicable regulations.

Eforts to recapture dissolved or suspended nutrients from farm effluents have included the production of other economically important aquatic species such as agar-producing algae and mussels. In the North Central Region, diverting nutrient-rich effluents into secondary crayfish or baitfish ponds may be effective in reduce waste products while providing an additional crop.

Wetlands have been used as ‘biological sponges’ to remove nutrients from water by slowing the water which allows solids to settle out and wetland vegetation to absorb nutrients.

Aquaculture facilities located on or adjacent to traditional agricultural fields may be able to take advantage of the Wetlands Reserve Program managed by the Agriculture Stabilization and Conservation Service. The Wetlands Reserve Program takes agricultural land out of production through payment to landowners for permanent conservation easements. However, if the amount of solid wastes produced by a fish farm exceeds the capacity of the wetland to process the material, the wetland will fill in and loose its effectiveness. Certain types of endangered and threatened natural wetlands communities may also be adversely affected by the addition of fish farm wastes.

Bibliography

National Research Council. 1993. Nutrient requirements of fish. National Academy Press. Washington, D.C. 114p. (Available from: National Academy Press, PHONE: 202-334-3313).

Piper, R.G., McElwain, I.B., Orme, L.E., McCraren, J.P., Fowler, L.G. and J.R. Leonard. 1982. Fish Hatchery Management. United States Department of the Interior Fish and Wildlife Service, Washington, D.C., USA. (Available from: American Fisheries Society, PHONE: 412-741-5700).